Characterization and relative sag source location in an electrical Distribution System

Caracterización y ubicación Relativa de fuentes de Hundimientos de voltaje en un Sistema eléctrico de distribución

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ABSTRACT

This article aims to show the development and implementation of an algorithm in Matlab to characterize and determine, in an electrical distribution system, the area where the presence of sources of voltage sags. IEEE 37 Node Test Feeder and ATP software were used and faults of different nature were simulated in different parts of the system. From the raw information obtained in the simulations, the data processing is performed to proceed to implement and probe the algorithm in Matlab, which took into account factors such as system topology and comparison of measurements given by strain gauges which were placed in the distribution system and whose information is used to characterize and determine the relative sag source location. Once the algorithm is developed, its effectiveness according to the behavior of the simulated system was evaluated.

In this paper a review of relative sag source location is shown. At once, the test feeder model used for the simulation of faults is displayed, and the algorithm developed to determine the relative sags source location in the distribution system. The following are show simulated failures in the system and the results obtained by the algorithm, establishing its effectiveness and finally the conclusions and recommendations tossed the development of this project is.

Keywords: Algorithm, Distribution System, Modeling, Location, Voltage Sags.

RESUMEN

Este proyecto tiene como propósito mostrar el desarrollo e implementación de un algoritmo en Matlab para caracterizar y determinar, en un sistema de distribución, la zona donde hay presencia de fuentes de hundimientos de tensión. Para desarrollar y probar este algoritmo, se utilizó un sistema de prueba de IEEE de 37 nodos, modelado en el software ATP, y se simularon fallas de diferente naturaleza en distintos puntos del sistema. A partir de la información en bruto obtenida en las simulaciones, se realizó el tratamiento de datos para proceder a implementar el algoritmo en Matlab, el cual tuvo en cuenta elementos como la topología del sistema y la comparación de las medidas dadas por medidores de tensión que fueron ubicados en el sistema de distribución y cuya información se usó para poder determinar la ubicación relativa de fuentes de hundimientos. Una vez desarrollado el algoritmo, se evaluó la efectividad del mismo de acuerdo con el comportamiento del sistema simulado.

En este documento se muestra una reseña sobre ubicación relativa de fuentes de hundimientos de voltaje, a continuación se muestra el modelo del sistema de distribución utilizado para la simulación de fallas, y el algoritmo desarrollado para determinar la ubicación relativa de fuentes de hundimientos de tensión en el sistema de distribución, a continuación se muestran las fallas simuladas en el sistema y los resultados arrojados por el algoritmo, estableciendo así la efectividad del mismo y finalmente se muestran las conclusiones y recomendaciones que arrojó el desarrollo de este proyecto.

Palabras clave: Algoritmo, Sistema de distribución, Modelación, Ubicación, Hundimiento de voltaje.

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I. Introduction

Power systems, divided into generation, transmission and distribution, are aimed at the demand of energy and are sufficiently known. Therefore, an important part of the power systems is the distribution system, through whom, the user, whether residential, commercial or industrial, comes to make use of the electrical energy supplied by the network operator according to energy demand, so it is necessary that there are no fault conditions present in the system, and if they occurs, it must be fixed up in the shortest possible time, keeping the system under normal operating conditions that allow the reliability, stability and a high level of power quality.

Hence, it has become essentially look for ways to identify at what point of a distribution system faults occur, so that they can be identified according to their characteristics and thus be able to maneuver and take actions that reduce the impact of these faults on the rest of the system. So far, it is not possible to accu-

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rately identify the fault location. An alternative is to place meters along the network, so that by comparison of measurements that these capture, it is possible to identify the area which occurs to minimize the impact of faults and reduce costs associated with them. And hence, a configured application is required to determine the relative sag source location and which is characterized by having high effectiveness.

II. Background

In recent years there has been a lot of work related to processing the raw information of voltage sags. This processing has been directed to the detection, classification, characterization and origin of voltage sags sources. Multiple tools have been used for the above purposes: Fourier transform, Wavelet transform, Kalman filters, and multivariable regression methods, among others.

The principles used for the detection and the origin of sags sources have also been diverse: quantification of the maximum energy and power (Kong Dong and Cheng, 2008) (Parsons, Grady, Powers and Soward, 2000); changes imped-ANCE seen by distance relay (Faisal Mohamed and Shareef, 2011), (Correa, Tumialan and Moreno, 2015); changes in the slope of the line (Li, Tayjasanant, Xu and Li, 2003), changes in the compo-nents current assets (Hamzah, Mohamed and Hussain, 2004); changes in the resistive impedance component, comparison of magnitudes of voltage dips on either side power transformer (Leborgne and Karlsson, 2008); definition of indicators and decision criteria to identify the source (Seon Dong Il and Seung, 2005), etc.

With a careful reading of the works we can conclude the following related with processing and, above all, the source of voltage sags:

The exact location of the source or origin of a voltage sag is too big a job. The technical literature reports only a precise location oriented work (Kazemi, Mohamed, Shareef and Rahi, 2014). The algorithm is called GACP-MVR, which is based on a multivariable regression model (MVR). According to the algorithm, first the optimal number and location of power quality monitors is determined and then the Mallow's Cp index is applied. Monitored busbars are considered as independent variables. Then, regression coefficients are obtained to estimate voltages at the not monitored busbars. The MVR trained models are used to determine the maximum voltage deviation and the minimum standard deviation data which sags sources are identified. The algorithm has the disadvantage that in addition to voltage measurements are required necessary training data (from simulations) where it is desirable to know what the behavior of the sags on the unmonitored buses. This training consists of a considerable number of simulations with varying impedances of failure, failure types, load increases and other parameters of interest. All aimed at understanding the behavior of unmonitored nodes.

As relative location (definition of an area, a section or group of sections which can come voltage sags) has the following:

Work (Blanco, Petit, Ordoñez and Barrera, 2013) provides the relative sag source location (meters downstream, upstream of meters, between meters) with voltage information. The algorithm considers only sags caused by faults in the network and information from at least three monitors located in the distribution network under study. Additional features of the algorithm are as follows: The descriptors are fundamental positive sequence voltages during the fault and during prefault; a number of failures is generated by ATP in a test system and the resulting information (voltage) is transferred to MATLAB with relative identification purposes (on descriptors compared with defined thresholds).

In (Barrera, Meléndez, Herraíz and Sánchez, 2009) the algorithm provides relative location (upstream or downstream of a power quality monitor). The algorithm is very simple: It is based on the calculation of the ratio of the currents of positive sequence before and during a fault in a power system.

Work (Hamzah, Mohamed and Hussain, 2009) presents an algorithm with the product of the effective current used and the power factor at the monitoring point. The basic idea, then, is to draw a graph with the evolution of this product over time. The location of the sag is determined by examining the index of the current component (ICC) at the beginning of sag. If the index is greater than before the sag occurs, then the sag occurs downstream, otherwise sag occurs upstream. In the algorithm data streams and power factors it is needed in the monitoring point.

One of the classic articles related to location of sources of voltage sags is (Leborgne and Karlsson, 2009), which only requires information of voltages. The source of the sag is located with magnitudes of sag in the primary and secondary sides of a power transformer. The main focus is the location on the edge or border point between two transmission systems. The idea is to compare the magnitude of sag, in per unit, based on the pre-fault voltage on both sides of a transformer. Two voltage drops according to a fault current and impedance transformer are defined and a comparison is made to determine whether the sag upstream or downstream of the transformer is presented.

In 2002 (Qader, Bollen and Allan, 1998), an article on the stochastic prediction of voltage sags in a transmission system was published by using two methods. The first method is the fault position which is most suitable for implementation in a software tool. This method was used to locate areas where sags are produced and for the frequency with which sags in each of the busbars presented. The other method used was that of critical distances. This method is appropriate to calculate how often sags occurring in a number of buses. Because this method is based on mathematical calculations that are made by hand and given the complexity of the calculations, the results are very limited to simple cases. One made up of 97 nodes, 400 kV, corresponding to a part of the transmission system in England and Wales system was used for this case study.

Moreover, a paper (Galijasevic and Abur, 2002) about troubleshooting using voltage measurements was published. The work consisted in taking actual measurements of voltage sags in certain nodes of a system and from these measurements, the system is modeled and areas with greater likelihood of failure were estimated and conducted the simulation with several fault resistances. After having the simulation results and using fuzzy logic, it came to check that the measurement results obtained by simulations, emulated almost precisely the values of actual measurements.

Finally, an article (Pereira, Da Silva, Kezunovic and Mantovani, 2009) on the use of an algorithm in order to locate faults was published, which generated sags in the power supplies of a distribution system. The basic principle of the algorithm is that when a fault occurs in the power sources, the propagation has different characteristics in each of the nodes which is connected a power supply and, therefore, by knowledge of these characteristics, it is possible to locate the node with faults or the area where failure of the power supply occurs. This approach ensures the efficiency

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of the algorithm which provides suitable results. For the case study, a real 13,8 kV system, consisting of 134 nodes it was used.

The main contribution of this paper is validating the algorithm developed by (Blanco, Petit, Ordóñez and Barrera, 2013) and characterization (cycle to cycle) of the sags, according to Bollen Classification. With this classification it is possible to determine the type of fault that originates the sags.

III. Description of the distribution system modeling

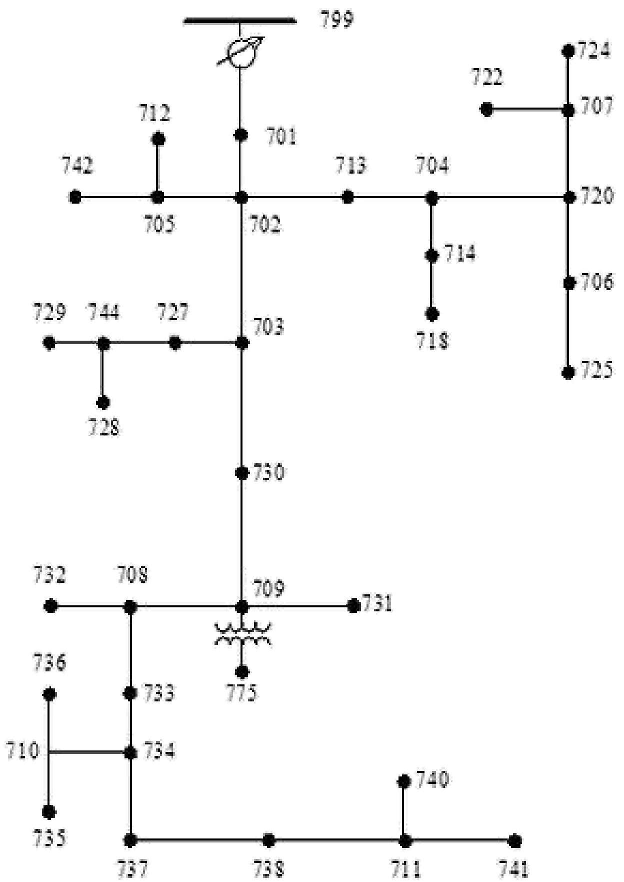

Figure 1. IEEE 37 Node Test Feeder.

For the development of this application, the IEEE 37 Node Test Feeder was used (Figure 1). This system of distribution is radial, which is quite convenient for the analysis, taking into account that the application has consistent results mostly for radial distribution systems, it means that each meter should be located on the main feeder system consecutively and not in the branches or laterals of the system or endpoints.

There is a voltage regulator in node 799, which allows the voltage supplied to the system is always the same value and has no abrupt changes in time, so that the RMS value is constant.

Modelling the system in ATP software, this is controlled by a generator, which fulfills the same function that the regulatory change that is always giving the same RMS value as a function of time.

In node 709, according to the IEEE model, the transformer is delta-delta with a capacity of 0,5 MVA and 4,8 kV transformer ratio to 0,48 kV. In the simulated system, the transformer used differs with the IEEE only in that the model is delta-Y. This is in order to be able to model ground faults and watch the behavior of the system and performance of application in this type of failure.

To verify that changes made in the system did not affect the nature of the topology and, after completing the modifications, we proceeded to perform a simulation of the system without faults that originated sags. In this case, voltages in nodes, currents by branches and reactive and active power were observed. From these data, we proceeded to compare them with results from the load flow information that appears on the test system. This observation show similar data, so that the viability of the changes was defined and that they did not have inconsistencies that could affect the development of the tests.

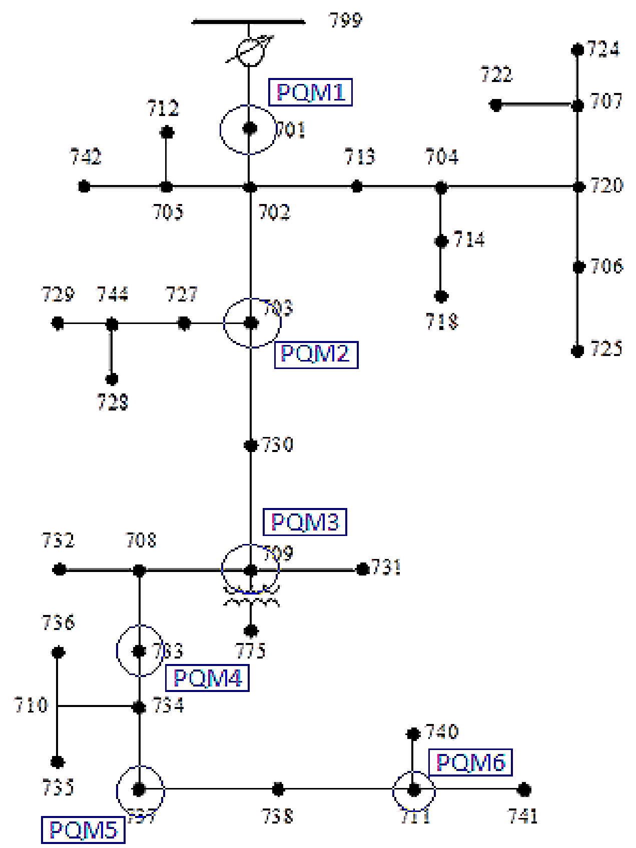

Figure 2. Distribution of voltage meters in the Test Feeder

Six meters were placed in model of the system, which store data of node voltages: the gauge number one located at node 701, the meter 2 at 703 node, meter 3 at 709 node, the meter 4 at node 733, the meter 5 at node 737 and, finally, the meter 6 is located at 711 node.

The meters are distributed along the main feeder distribution system, which is radial. This distribution is because the application does not work properly when the system is meshed, or the meters are in remote branches, or laterals, to the main feeder.

To simulate faults at first two-phase and three-phase faults were simulated, but it was not possible ground faults due to the connections of the main transformer, so it was established right put down transformer 230 kV to 4,8 kV and connecting to earth for

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the purpose of generating single-phase and two-phase to ground faults. Also, changes in impedance fault, fault clearing time, fault location and type of fault which caused a large number of faults were generated.

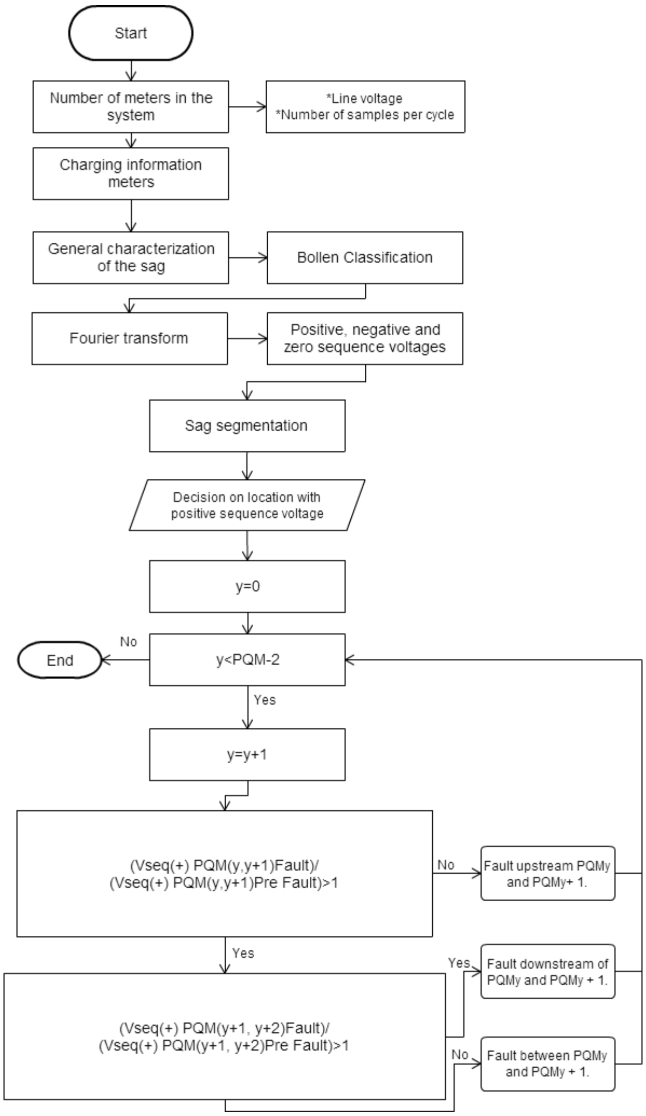

Figure 3. Description of application for characterization and voltage sag source location.

The purpose of the application is to locate the area where the sag had occurred. This application was developed from the algorithm implemented by (Blanco, Petit, Ordoñez and Barrera, 2013), since this algorithm was proposed to implement a more detailed characterization of the sag located, from the Bollen methodology.

This is done with simulated values before and during voltage sag generated by ATP software. The application, implemented in Matlab, receives raw data from ATP, and then the data obtained, shows the RMS values of the voltages, then performs the characterization of sag, ie the RMS values obtained values prefault is obtained and misses sag, considering that the sag starts when a value below of 0.9 p.u. is presented in the RMS value of the voltage wave.

After obtaining the values (duration and magnitude), the sag is classified according to Bollen methodology (Bollen, 2000), taking into account the displacement in phasors, the fall in the magnitude and type of fault. This classification throws a letter between A-G according to the sag detected by meters. One example of results for this basic characterization, for each monitor, is showed in Table I.

Table 1. Basic characterization of sags, by each monitor.

PQM	Magnitude [p.u.]	Duration [s]	Type (per cycle)
1	0,802	0,05	E-E-E
2	0,647	0,063	E-E-E
3	0,645	0,061	E-E-E
4	0,645	0,061	E-E-E
5	0,644	0,060	E-E-E
6	0,645	0,060	E-E-E

After characterization, the Fourier transform is applied to raw information of voltages (time domain). Taking into account that in ATP only magnitudes are obtained, it is necessary decompose the wave using the Fourier transform with the purpose to obtain the voltage phasor (Magnitude and angle), this procedure repeats for each phase. With this information afterwards it performs decomposition in positive, negative and zero sequence components. It should be noted that the priority will be the positive component of voltage, because this component is presented in all types of faults.

The sag's segmentation is carried out in order to have a value from the sag for later evaluation in the block of the algorithm's decision either in fault state or pre-fault state.

Finally the application use the information obtained previously (Positive sequence component and sag's segmentation) to determine the relative location where the sag occurred in the system. It is important take into account that a control index (y) is used in this step given the number of iterations.

To test the application, a total number of 120 faults were made. Table 2 shows the number and type of faults and the relative location of sags sources

Table 2. Type and number of simulated faults in the distribution system.

Faults between PQM1-PQM2	L-L	8
	L-L-L	13
	L-L-G	13
	L-G	13
	Total	**47**
Faults between PQM2-PQM3	L-L	3
	L-L-L	2
	L-L-G	2
	L-G	3
	Total	**10**
Faults between PQM3-PQM4	L-L	4
	L-L-L	4
	L-L-G	2
	L-G	5

	Total	**15**
Faults upstream PQM1-PQM2	L-L	2
	L-L-L	2
	L-L-G	1
	L-G	1
	Total	**6**
Faults downstream PQM3-PQM4	L-L	8
	L-L-L	11
	L-L-G	12
	L-G	11
	Total	**42**
Total simulated faults		**120**

IV. Results of the application.

In this work, 120 faults were simulated in ATP software for test feeder. The corresponding results were processed in the application implemented in Matlab, which showed the relative sag source location and characterization of each one. In Table 3 is listed the simulated faults in the system shown that all failures were correctly located by the algorithm. It is noteworthy that the algorithm, when it sees a failure so far the meter 4 is not strict to show if the fault is between PQM4 and PQM5 or downstream of PQM5. The application only shows directly that is downstream of the meter 4 is why even if not through about the last 2 meters, taken as true that the fault is downstream of the meter 4. Table 4 shows detailed information so that the algorithm throw in some simulated failures.

Table 3. Results obtained by the application

Relative Location	Faults (source of sags) correctly located	Faults (source of sags) incorrectly located.
Upstream PQM1-PQM2	6	0
Between PQM1-PQM2	47	0
Between PQM2-PQM3	10	0
Between PQM3-PQM4	15	0
Downstream PQM3-PQM4	42	0

According with simulations and experimental results worth analyzing they were obtained:

At least one of the monitors must detect the sag, but in this case all the information of other monitors is necessary for voltage sag source location.

Also, established the need to take samples from 10 cycles before and 10 cycles sag occur after the failure, so they reach store all the required values for the corresponding correlation analysis voltage to allow locate the region where the fault occurs.

Table 4. Some detailed results of the application.

Fault in node	Relative Sag Source Location	Fault type (Source of Sag)	Sag type
703	PQM1-PQM2	L-L-G	E
730	PQM2-PQM3	L-L	C
733	PQM3-PQM4	L-L-L	G
741	DOWNSTREAM PQM3-PQM4	L-G	B
Prim. Regulator	UPSTREAM PQM1-PQM2	L-G	B
733	PQM3-PQM4	L-L-L	G-A
724	PQM1-PQM2	L-L-L	A

Among the results, it could find that once the relative sag source location is done (location of the region where the sag occurs), the application threw a 94% effectiveness in 120 samples taken, even though the 6% remaining was not correctly located, it should not be understood as a lack of the application. Regarding the Bollen classification, it was found that 97% of the samples are classified within the classification of Bollen and 3% were not classified, this 3% belongs to some series of sags which cannot be classified by Bollen. Table 5, shows the percentage of sags that were found in each category of Bollen in the simulations. In some cases, the same sag was classified in two categories, this occurs because a phase shift caused by sag's occurrence.

Table 5. Percentage of effectiveness of sags classification.

Bollen Classification	Samples	%
A	6	80%
B	35	100%
C	24	100%
D	0	
E	21	100%
F	0	
G	20	80%
No classification	4	
With two categories	10	
Total	**120**	**100%**

V. Conclusions.

It is important to highlight the advantage of use only voltage values to determine the relative sag source location, because in the system can always find these values, but it is not always easy to obtain values of currents. This makes it more feasible and less complicated to determine the location of the sag in the distribution system, without needing to other measuring instruments that are not in the system.

The application identifies regions that may become more susceptible to failures and likewise identifies the type of sag which makes it possible to establish that a region can become more susceptible to certain types of faults, which can lead to losses in equipment and production which in the end translates into economic losses for both, the industrial sector and to network operators. This will help make the system more reliable and both, system operators and users (particularly for the industrial sector), are less affected by the consequences that generates a sag.

One of the drawbacks of the application is to reduce the region and give a more accurate location point of faults necessary to have more meters within the system, which is not always easy, plus the algorithm is formulated in such so that the meters are along the main feeder in the distribution system, which means that if on one of the branches (laterals) of the feeder fault occurs and this branch contains many nodes, it is not possible to establish the precise location of failure within the system and other analysis and measures to more effectively determine the region where the failure occurs may be necessary.

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